IMPROVED MODELING OF DROP VAPORIZATION AND COMBUSTION IN DIESEL SPRAYS

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SUMMARY/OVERVIEW

This program focuses on modeling the vaporization liquid drops and the penetration of the liquid phase in Diesel sprays under cold-start conditions. This work is carried out within the framework of multidimensional modeling of the physical processes in Diesel engines. In the prior reporting period, it was shown that though vaporization of the drops under warm operating conditions may be mixing controlled whereby the drop vaporization characteristic time is much shorter than the mixing time, the vaporization rate under cold-start conditions may not be assumed to be mixing controlled. Hence, drop size effects have to be considered under cold-start conditions. In this work, a drop vaporization model under high pressure conditions is included within the context of a locally homogeneous flow assumption.

TECHNICAL DISCUSSION

Under warm operating conditions in a Diesel engine, the chamber temperature would be about 1000 K or higher, and densities would be in the range of 15-30 kg/m^3. During cold start, the temperature may be less than 800 K and the densities lower that 15 kg/m^3. Under such conditions, the characteristic time of drop vaporization may be longer than the characteristic time associated with mixing in the spray. Hence, the accuracy of drop vaporization models that predict the vaporization characteristic times becomes an important factor in predicting spray penetration and fuel-air mixing when employing multidimensional models.

A summary of prior work on this topic as part of this research program will now be given. Several findings have been made. It has been shown that supercritical droplet vaporization is not likely to occur in Diesel engines under warm operating conditions and even less likely under cold-start conditions [1]. A phenomenological model for multicomponent droplet vaporization has been developed, implemented in the multidimensional code and computations carried out [2]. Under cold-start conditions the distribution of the different components of the fuel species may be different, and it may be important to include such effects in predictive models. But, this effect is not important under warm operating conditions. It has also been shown that the simplified models for droplet vaporization that are employed in multidimensional codes such as KIVA overpredict the droplet vaporization by about 30% under warm operating Diesel conditions [1]. This difference is not a factor that affects liquid vaporization in Diesel sprays under warm operating conditions when the vaporization characteristic times are much shorter than the mixing

characteristic times [3-5]. Under cold-start conditions, the vaporization times become of the same order or longer than the characteristic mixing times. Under such conditions, it is essential to model drop vaporization processes with adequate accuracy. It has also been shown that, from the point of employing droplet vaporization models in multidimensional models, a severe limitation is related to the inability to employ adequate grid resolution in the region close to the orifice [6-7]. This limitation arises as a result of employing the Lagrangian Drop Eulerian Fluid (LDEF) approach to modeling the liquid drops and makes it difficult to assess the accuracy of vaporization models by employing multidimensional models.

To overcome the limitation highlighted above, a locally homogeneous flow (LHF) approximation was employed to model the sprays and study the physics [4, 8]. In this case, adequate resolution can be employed. Figure 1 shows a typical grid employed for the computations whose results are presented below. The grid employed for the LDEF computations and the LHF computations are shown. It may be seen that with the LHF computations, grid sizes of an order of magnitude greater than for the LDEF computations may be employed. In the LHF approximation, it is assumed that the liquid and gas velocities are identical. This assumption is reasonable when injection velocities are over 300 m/s, the drop sizes are of the O(10 μm) or less and the Stokes numbers are small. In prior work that has been discussed in the literature, a model for drop vaporization has not been included within the LHF formulation [4]. Vaporization has been assumed to be mixing controlled. In this work, we have developed an approach to include drop size effects and, hence, drop vaporization under high pressure conditions within the formulation of the LHF model. This may then be employed to study Diesel spray and vaporization characteristics under cold-start conditions [5].

Results are shown below when this vaporization model is employed for Diesel sprays . Figure 2 shows computed and measured overall spray penetration characteristics over a wide range of ambient densities. The measurements are those reported by Naber and Siebers [9]. It may be seen that the computed and measured penetrations show agreement within 5% for the range of conditions considered. Figure 3 shows computed and measured entrainment velocities in a spray at three axial locations as function of time after start of injection. The measurements are those reported by Cossali et al [10]. Again, the trends agree and there is quantitative agreement within 25%. Figure 4 shows computed and measured liquid penetrations in a Diesel spray when the injection pressure is changed, The Lagrangian-Drop-Eulerian-Fluid (LDEF) approach and the LHF approach with droplet vaporization effects are employed to compare the computed results with the measured ones. The measurements are those reported by Siebers [3]. Results for ambient densities of 30.2 kg/m^3 and 7.2 kg/m^3 are shown. The LDEF results are shown for the case with ambient density of 30.2 kg/m^3. It is seen that the computed results with the LDEF approach do not agree with the measured trends, but the results obtained with the approach developed here do give trends comparable to the measured trends. Figure 5 shows measured and computed liquid penetrations when the chamber density is changed. The figure shows two computed curves: One is obtained with the LHF model with the mixing controlled model for vaporization and the second one with the high pressure vaporization model developed here. It may be seen that the results with the vaporization model show trends that agree with the measured trends. Figure 6 shows computed and measured steady liquid penetrations as a function of ambient temperature for two different values of ambient density. Adequate agreement in trends is shown.

ACKNOWLEDGMENTS

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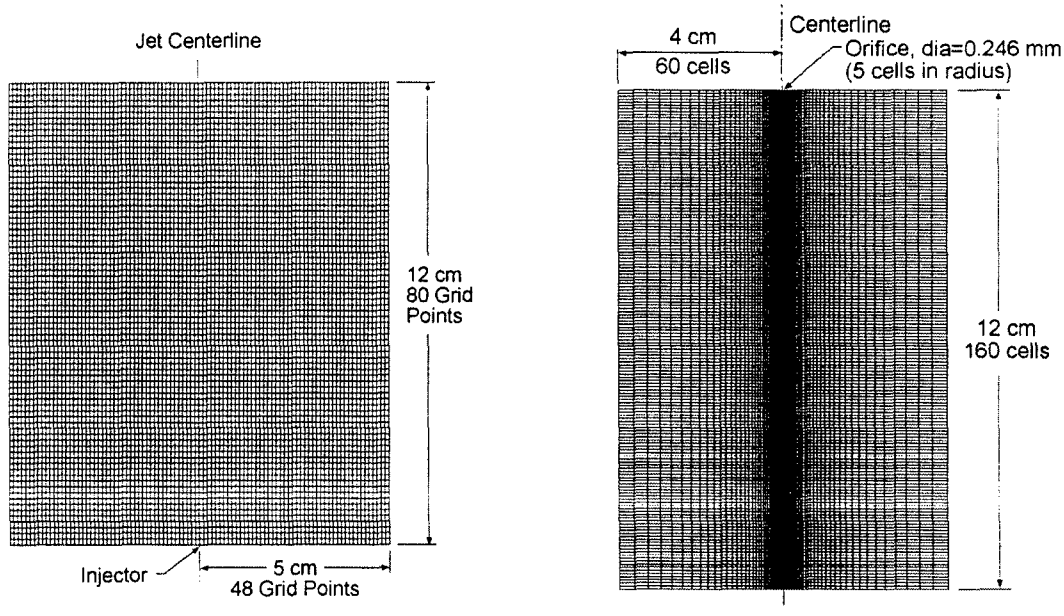

(a) LDEF grid. (b) LHF grid.

Figure 1. Computational grid.

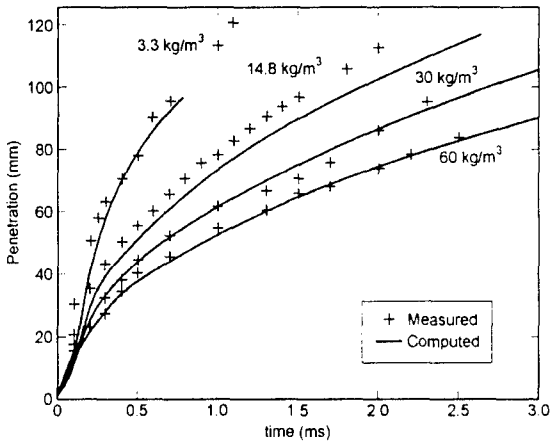

Figure 2. Spray penetration vs. time after start of injection.

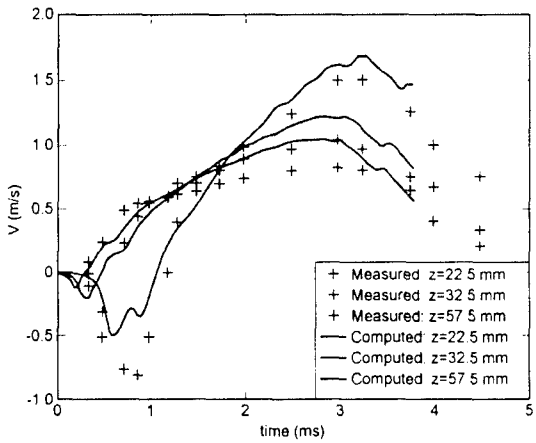

Figure 3. Computed and measured entrainment velocities as a function of time after start of injections. (T=298 K, ρ=7.02 kg/m^3, U_{inj}=230 m/s)

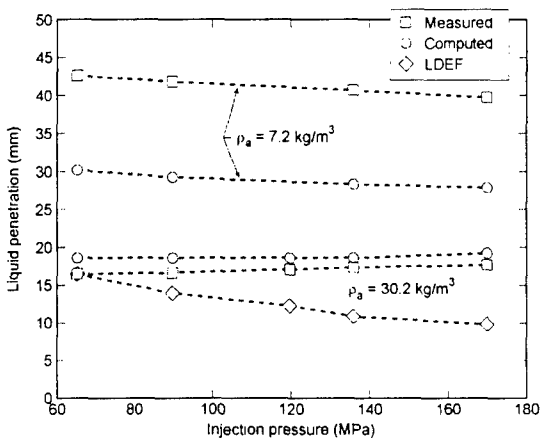

Figure 4. Liquid penetration vs. injection pressure. (T_a=1000 K, d_{orif}=0.25 mm)

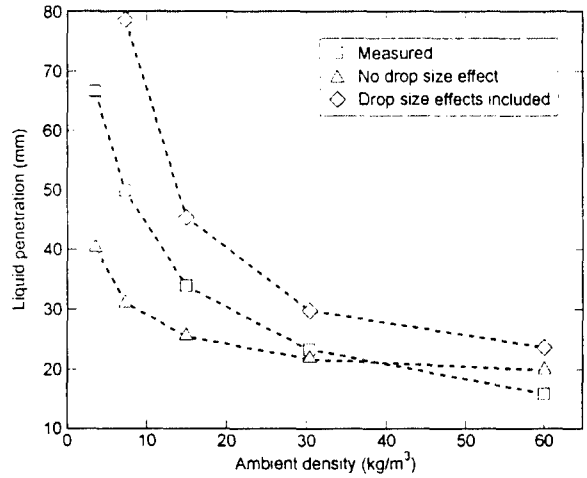

Figure 5. Liquid penetration vs. ambient density. (T_a=850 K, P_{inj}=136 MPa)

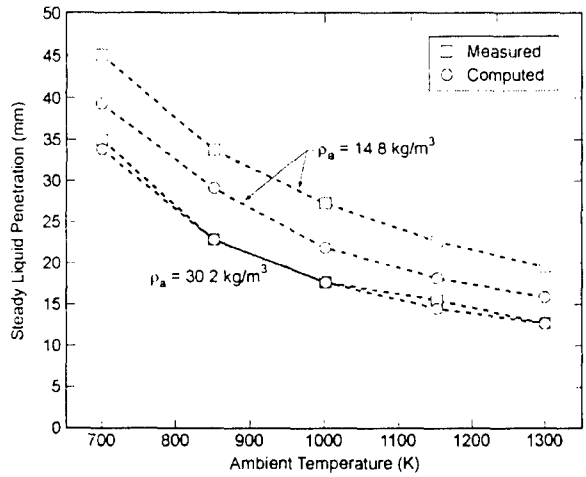

Figure 6. Liquid penetration vs. ambient temperature. (ρ_a=30.2 kg/m^3, P_{inj}=136 MPa, d_{orif}=0.25 mm)